COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

June 1952

Within the shadows of the coal pile

Centrifugal Pumps for Feeding High-Pressure Boilers

Use of Ultrasonic Coagulator with a Cyclone Separator

Chemicals, Pipeline Gas and Liquid Fuels from Coal

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COMBUSTION

Editorials

Boiler or Steam Generating Unit?

Webster's Dictionary defines a boiler as "that part of a steam generator in which water is converted into steam, consisting usually of metal shells, headers and tubes that form the container for the steam and water under pressure."

In recent years, with the subordination of convection steam-making surface to superheater, economizer and air-preheater surfaces, the terms "steam generating unit" and "steam generator" have gained favor; not only in the larger sizes, but also for small capacities, particularly to designate a self-contained unit incorporating the essential auxiliaries.

Despite this, the term "boiler" persists, even to a considerable extent in central station parlance where such operating designations as "Boiler No. 1," Boiler No. 2," etc., are common. Furthermore, one finds such top organizations as the Edison Electric Institute and the Association of Edison Illuminating Companies differing in this respect. The former issues per'odic printed reports of its Prime Movers Committee under titles of "Boiler and Combustion" and "Boiler Auxiliaries," whereas the Power Generation Committee of the latter organization, in its annual reports, always lists the "steam generators" ordered during the current year. Similarly, there is lack of uniformity in the literature issued by equipment manufacturers. Reverting to the Webster definition, it will be noted that this takes cognizance of "steam generator" and narrows the boiler to that part in which steam is generated under pressure. This would appear to preclude the economizer, superheater and air preheater as a part of the boiler and substantiate use of the broader term to designate the complete unit.

On the other hand, the advent and wide application of the single boiler per turbine generator as an operating unit offers possible room for confusion between references to steam generating units and electric generating units.

One justification that has been advanced for use of the word boiler to describe a complete steam generating unit is that words characteristically grow in meaning to encompass new or broader concepts of their original meanings. Thus the word boiler is today understood by many to designate the whole of a modern steam generating unit, whereas thirty years ago, in the pre-water-cooled furnace era, its use was restricted to the drums, tubes and headers which comprised the boiler proper. With the development of modern units, characterized by integrated overall design and supplied as a whole by one manufacturer, the boiler as a separate entity has practically disappeared, but the name has persisted. Thus the name has evolved along with the equipment.

It does not require much searching to reveal that engineering is not only full of non-descriptive terms whose origin bears little relation to present application, but that there are frequently inconsistencies in their use. Both boilers and steam generators have their proponents who undoubtedly are prepared to defend their preferences. It is a subject that warrants further constructive discussion in the interest of establishing a maximum degree of uniformity in technical nomenclature.

A Lesson in Engineering Fundamentals

Recently in a New England city a public hearing was held concerning the possible construction of a steam-electric generating station at a location to which the local residents had considerable objection. This is not an uncommon procedure, particularly when public utility companies are planning new power plants in areas which have considerable value for commercial, residential uses. But there was one distinguishing feature that prompts this editorial.

One of the consultants for the electric company was Dr. Alexander G. Christie, professor emeritus of mechanical engineering at The Johns Hopkins University and a past president of The American Society of Mechanical Engineers. Throughout his long and distin-

As described in one of the most highly reputed newspapers in New York City, the local residents—in effect—greeted the consultant with catcalls and jeers when he testified that a light, sand-like material (fly ash) would be emitted from the stacks of the proposed station. But the *coup de grace* was administered by the local legal counsel when he "compelled" Dr. Christie to admit that the condensing water discharging from the plant would be capable, in certain seasons of the year, of raising the temperature of the sea water in the nearby inlet to a point where swimming might be uncomfortable. This revelation of a fundamental engineering principle apparently heightened the objections of the local inhabitants, although no one seemed to be cognizant of the fact that this same heat rejected by the condenser might also serve to lengthen the swimming season and even assist in minimizing the damaging effects of large ice movements during the winter season.

guished engineering career Dr. Christie has achieved a professional reputation that commands recognition wherever power plants are built and operated. Yet even that was not enough to forestall the "spectacle" that was reported to have taken place at the public hearing.

The newspaper account did not mention the consultant's reaction to the criticism and derision to which he was subjected. But when appearing before a public gathering and testifying on technical matters upon which his competence is unquestioned, an engineer of Dr. Christie's professional standing certainly deserves far greater respect than he was reported to have been accorded.

Centrifugal Pumps for Feeding High-Pressure Boilers

A discussion of basic design features including types of casing, impellers, diffusers, shafts, stuffing boxes, bearings and materials of construction; also suggestions on selection in order to assure maximum reliability, durability and availability.

By F. B. APPLEGATE
Engineer, Pacific Pumps, Inc.

EVERY step in the design and manufacture of a centrifugal pump for feeding high-pressure steam boilers is dominated by a "must." As a foundation, the pump must have reliability, durability and availability of the highest order. It must be capable of picking up the load at a moment's notice; its performance must be stable from zero to maximum capacity; and it must have maximum resistance to corrosion-erosion.

Reliability, defined as "dependable, trustworthy" and durability, defined as "the power of resistance to destructive agencies" are affected by design, materials and workmanship. Design, form and proportions must be developed, first, for mechanical reliability, and, second, for durability, the latter involving both mechanical wear and corrosion-erosion. Precision workmanship is a must. The effects of poor workmanship, particularly sloppy fits between areas of high and low pressures, will be apparent after a brief period of operation.

Availability may be defined as "the state or condition of readiness for operation." The potential availability is determined by design, materials and workmanship, but the conversion of potential to actual availability is determined by how the pump is installed, operated and maintained.

Basic Design

A basic design favored for high-pressure boiler-feed service is the diffuser pump with single-suction impellers facing in one direction. Mechanically, the design provides the maximum number of duplicate parts of the simple, circular form and uniform section so easily fabricated in either carbon or chrome alloy steels. The design is hydraulically efficient, it provides perfect radial hydraulic balance and controlled axial hydraulic balance.

The Pump Case

The pump case is a major item in the design of high-pressure boiler feed pumps. Two types are in general use. One, designated as the radial split (also barrel or vertical split type), is of true cylindrical form with circular joints in a plane at right angles to the longitudinal axis of the case. The other, designated as the axial split (also horizontal split), may have either a true or modified cylindrical form, split in halves with flat joints in a plane parallel to the longitudinal axis of the case.

Because of the perfect symmetry of the radial-split case it can be produced either as a casting or as a forging. The top pressure limit for a cast case is approximately 1500 psi. The heavy metal sections required for pressure above 1500 psi make it difficult to produce pressure-tight castings in either carbon or chrome alloy steels. The forged-steel case, because of assured soundness and uniform strength, is applicable for all pressures and is preferred by many users for pressures down to 1000 psi.

The radial-split case requires two ring-type joints, one subjected to suction pressure and one to discharge pressure. Both joints are of relatively small diameter and are easily held tight under high pressures.

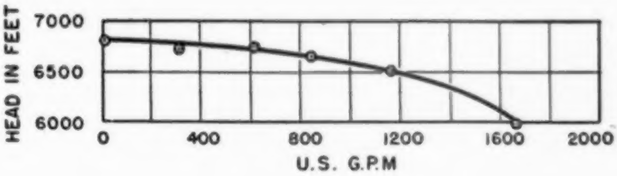
To avoid eccentric strains from piping the suction and discharge nozzles are located on the vertical centerline of the case. They can be made for either flanged or welded pipe connections and can be located on either the top or bottom of the case.

Application of the axial-split case to high-pressure boiler-feed service is limited by the combination of design form, unbalanced proportions, unequal distribution of stress and the characteristics of cast materials. There seems to be considerable difference of opinion as to the actual pressure limits of the axial split case. Many experienced engineers prefer a top limit of 1000 to 1100 psig; the more optimistic advocate a top of 1600 psig and the extremists forecast 2400 psig or more as the top.

When the pressure in an axial split case passes through the stable and enters the critical range, there is a tendency to breathe at the split joint. Breathing is usually followed by misalignment of the rotor, and, what is even worse, uncontrolled leakage. It is difficult to predict the maximum pressure the axial-split case will withstand without breathing. The pressure inside the case not only varies from stage to stage, but the point of maximum intensity may be at the center or at the end of the case depending upon the arrangement of the impellers. The stress on the bolting varies with pressure as well as stress caused by temperature changes. The magnitude and direction of the latter are unknown because of the unbalanced proportions and unsymmetrical form of the case.

Impellers

The preferred impeller is the single-suction enclosed type of one-piece construction. Use of this type reduces the shaft span appreciably and permits employ-



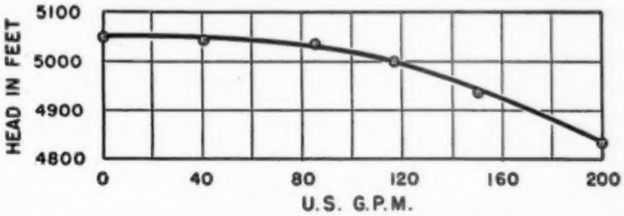


Fig. 1—Head curves for high-pressure boiler-feed pumps having multiple-vane diffusers

ment of interstage passages of simple form. Each impeller is dynamically balanced.

Impellers may be either a shrink fit or a close sliding fit on the shaft. When the accuracy of finish was measured in hundredths of an inch, the shrink fit was a necessity. Because of the accuracy of finish attained with today's machine tools, impellers can properly be fitted on the shaft without resorting to shrink fits.

Diffuser

The multiple-vane type diffuser, with the water passages between the vanes formed and proportioned to function as a series of equally spaced volutes, is preferred for high-pressure service. It insures equal pressure at all points on the periphery of the impeller, and this uniformity of pressure eliminates radial hydraulic thrust with its resultant shaft deflection.

The rather broad statement that the major disadvantage of the multiple-vane diffuser is the inherent droop in its head capacity curve as it approaches shut off is too often made without qualification. Actually, this droop is an inherent characteristic of the high-head, low specific speed impeller and its head-capacity curve will show this same droop whether the impeller be operated in a volute case without diffusers or an annular case with multiple-vane diffusers.

Typical head curves for high-pressure boiler-feed pumps fitted with multiple-vane diffusers are shown by Fig. 1. The points on each curve are plotted from actual tests of small and large capacity pumps. Each curve rises steadily without any indication of a "droop" as it approaches shut off.

The hydraulic designs of the impellers and diffusers for high-pressure boiler feed pumps are developed specially for the individual service. The entrance, curvature, and exit angles of the impeller and diffuser vanes together with the area of the water passages are carefully coordinated to insure maximum efficiency and to produce the desired head curve. The first stage or suction impeller is designed specially for minimum required NPSH.

The Pump Shaft

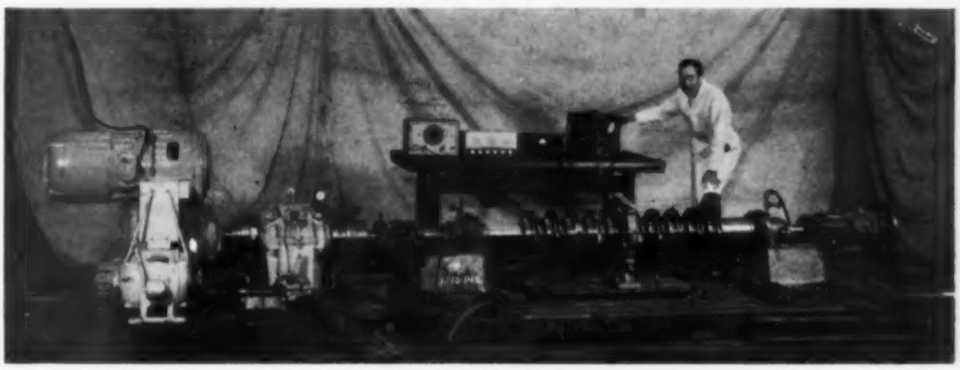
The principle of the absolutely rigid shaft for multistage pumps was based on the assumption that the first critical speed should be 20–25 per cent above the operating speed. This assumption was acceptable when 1750 rpm was the top operating speed. When the operating speeds were increased to 3600–5000 rpm, the diameter of the rigid shaft increased to a point where it was neither practical nor economical to use a shaft of this type.

For hydraulic reasons a shaft with a first critical speed below the operating speed is the preferred design. By using the smaller shaft the hydraulic efficiency of the pump is increased; the pickup speed for the suction impeller is decreased and less NPSH is required to prevent cavitation.

The critical speed of a shaft is determined by the amount of deflection that it will show and this deflection is dependent upon the weight of the rotating element and shaft span. All calculations for deflection are based on bare shafts. When the shaft is installed in the pump it is fitted with impellers, spacers sleeves and shaft sleeves, all of which stiffen the shaft. The calculations for deflection make no allowance for these factors, but research has proved that they actually stiffen the shaft and decrease its deflection.

Shaft stiffness and vibration were the objectives of a recent research project utilizing full size rotating elements at speeds up to and including 4000 rpm. The actual deflection of the shaft was measured with electrical instruments of extreme sensitivity and accuracy. Fig. 2 shows the rotating element of a ten-stage pump set up for deflection test. Actual operating conditions are reproduced by making the distance between the stuffing boxes and between bearings exactly the same as when the rotor is installed in the pump case. For this unit the first critical speed of the shaft was 2254 rpm and the magnitude of the vibration of the shaft passing through the critical speed was 0.0015 in. which is far less than the running clearances between the rotating and stationary parts.

Fig. 2—Rotating element set up for deflection test



The Stuffing Box

The stuffing-box packing is exposed to possible damage by hot feed water and by excessive friction between the packing and the rotating shaft sleeve. The stuffing box can be designed to insure the packing against damage by hot water but damage by excessive friction can only be prevented by the proper installation and maintenance of the packing.

Water-cooled stuffing boxes are accepted as standard for all feedwater temperatures. Generally, the boxes are packed without installing a lantern ring. However, the design should make provision for a lantern ring and connections for the circulating water, so that a lantern ring can be installed if desirable or necessary. The stuffing box gland should be the smothering type.

To be effective, the depth of the water jacket surrounding the stuffing box must be sufficient to cool all, not just part of the packing rings. Stuffing boxes of this type, packed solid (without lantern ring) are giving satisfactory service for 350 F temperature and 300 psig pressure. Operating records of three years with 300 F feedwater have been obtained without renewing packing.

Today, feedwater temperatures of 450 F and suction pressures of 475 psig are not uncommon. For such temperature-pressure conditions a stuffing box of special design with pressure-reducing sleeve and bleed off to a low-pressure chamber is used to reduce the pressure on the packing to 100–150 psi.

To prevent excessive friction with resultant damage to either or both the packing and shaft sleeve, it is necessary to permit a small amount of feedwater to leak out between the packing and shaft sleeve. The smothering gland will prevent the leakage from flashing and releasing vapors.

Another research project of major importance has for its objective a more efficient means of sealing the shaft in pumps for high-pressure, high-temperature services. This includes investigation of the efficiency of both liquid seals and mechanical seals. Although the project has not been completed, the data obtained has been extremely valuable in the development of mechanical seals which successfully handle water of very high temperature and presssure.

Bearings and Lubrication

Because of their reliability, durability and high factor of availability, sleeve, radial and Kingsbury thrust bearings are preferred types for high-pressure boiler-feed pumps. The bearing housings must be provided with effective end seals to prevent contamination of the lube oil by vapor, water or other contaminants.

The bearings may be lubricated by oil rings or they may be pressure lubricated, preferably the latter. The pressure lubrication system includes a submerged gear-type oil pump driven from the feed pump shaft, an oil reservoir, oil cooler, oil pressure gages and thermometers. The pressure system can be designed to lubricate the bearings of the pump only, or the bearings of the pump and driver.

Bearings designed for pressure lubrication should be fitted with oiling rings for starting and for emergency operation. This applies whether the system includes a hand oil pump or a motor-driven auxiliary oil pump.

Axial Balancing Device

A number of single-suction impellers, all facing in the same direction, creates an axial thrust toward the suction end of the pump. To balance this thrust and to reduce the pressure on the outboard stuffing box, a balancing disk, a combination balancing drum and disk, or a balancing drum and bushing may be used.

The balancing disk is the most efficient of the three basic types. It is non-seizing, easily maintained, easily repaired and easily restored to its original high efficiency. Because of these advantages it is a preferred type of axial balancing device.

Materials of Construction

The chrome-alloy steels have many characteristics which make them the preferred material for internal parts of high-pressure boiler-feed pumps. They are easily fabricated in the form required; they have the physical characteristics to withstand the stresses of service; they can be heat treated and hardened; they have high resistance to corrosive attack by hot feedwater; they are readily available; and they are economical to use.

Design form, design proportions and surface finish are major factors in developing fully the corrosion-erosion resistance of the material. High velocities, especially where turbulence with consequent cavitation is present, may cause a serious increase in the attack on an adjacent material. Highly stressed parts usually corrode more rapidly than low stressed parts. Sound smooth surfaces are more resistant to attack than scaled, spongy surfaces. Simple forms, uniform metal sections and surfaces with maximum exposure for inspection, thorough cleaning and smooth finish are basic requirements for maximum resistance to corrosion-erosion.

Selecting a Boiler-Feed Pump

The essential requirements to keep in mind when selecting such a vital piece of equipment as a pump for feeding high-pressure boilers are high availability, durability and low cost of maintenance. While initial efficiency is of economic importance, it is subordinate to essential requirements.

Design form, design proportions and workmanship determine the mechanical efficiency and these same factors plus material efficiency determine the availability, durability and cost of maintaining the pump. When evaluating the pump for mechanical efficiency it is best to use basic data which have been established by accurate tests. When evaluating other factors affecting the performance, the basic data are not so accurately established and dependence must be placed largely upon sound engineering judgment and the knowledge of experience for fixing the economic value of the factors which determine availability, durability and cost of maintenance.

Because wearing rings and bushings function as a pressure breakdown device between stages and not as bearings, there must be a uniform clearance between a stationary and the adjacent rotating part. The effect of this clearance upon the efficiency of the pump is quite marked. As this clearance is increased, the leakage from the high- to the low-pressure areas is increased, and since this leakage is a loss, the efficiency of the pump is decreased. Therefore, when guaranteed

efficiencies are used for evaluating bids, the clearance for each guarantee should be known and each adjusted to a common clearance. High initial efficiencies based on clearances so small as to be dangerous should be penalized. The final comparative evaluation can then be made using the adjusted guarantees as a base.

High velocities in the pump increase the possibility of erosion and high maintenance cost. The head per stage is indicative of the velocity of the water in the pump. Therefore, a pump developing 720 ft per stage has a lower availability and durability expectancy, together with a higher maintenance cost expectancy, than a pump developing only 600 ft per stage.

Parts of simple, regular design form and balanced proportions (uniform section) have a higher economic rating than parts of complex, irregular form and unbalanced proportions. The simple forms are easily produced, they are easily finished, especially surfaces that are not machined, and the balanced proportions prevent stress concentration and corrosion-fatigue failures. The complex forms are more difficult to produce as it is difficult and in some cases impossible to finish surfaces that are not machined. Futhermore, the unbalanced proportions create points of stress concentrations which may be of sufficient intensity to cause corrosion-fatigue failure.

Effects of Poor Workmanship

Quality of workmanship and precision finish are difficult to evaluate because they are invisible but the effects of poor workmanship and lack of precision are quickly visible. For example, the prevention of destructive interstage leakage is a necessity and the best means of preventing such leakage is a metal-to-metal seal between high- and low-pressure areas. The effectiveness of the seal depends upon the quality and precision of workmanship. If the seal faces are properly finished, the seal is tight. If the faces are not properly finished, water will leak from the high- to the low-pressure side. Once started, such leakage cannot be controlled and the effects will soon become visible. The jetting action on the low-pressure side will cause destructive cutting of the metal, loss of capacity, head and efficiency and increase outage and cost of maintenance.

Facts and Figures

West Virginia has now forged ahead of Pennsylvania as the nation's leading coal-producing state.

•

According to the Defense Electric Power Administration, an increase of 27 million kilowatts of new generating capacity in the three-year period, 1951–1953, will just about meet defense requirements as at present projected.

•

Many of the Nova Scotian coal mines extend far out under the Atlantic Ocean at depths ranging up to about 2500 feet.

•

According to *The Inch*, a publication of the Texas Eastern Transmission Corp., bamboo pipe lines nearly 3000 years old are still in use in Szechwan Province, China, for transmission of natural gas to salt evaporation houses as fuel.

•

The average weekly earnings of bituminous coal miners, according to figures released by the U. S. Bureau of Labor Statistics, for January 1952 was approximately $87.

•

The eminent scientist, Robert E. Millikan, is authority for the statement that the total available energy stored in coal and oil is many times greater than that stored in the unstable atoms of uranium and thorium.

•

The world production of oil has reached an all-time high of 12 million barrels a day, of which the United States produces more than half. The industry's drilling forecast for 1952 is over 45,000 new wells.

•

An increase of 50 deg F in initial steam temperature, from 1050 to 1100 F is generally considered to represent gain in efficiency of about 0.6 per cent.

•

Fission byproducts can be employed as a relatively inexpensive means of inspecting metals for internal flaws.

•

A recent paper before The Institution of Mechanical Engineers (Great Britain) states that the annual deposition of atmospheric dust per square mile in London has been estimated as between 250 and 300 tons.

•

Only about ten per cent of the manganese used by the American steel industry is supplied by American producers, the remainder coming from India, the Gold Coast, South Africa and Brazil, with small amounts from Mexico, Chile and the Philippines. Imports from Russia, the world's largest producer, have practically ceased.

Sales of Electric Energy

Electric power statistics issued regularly by the Federal Power Commission have now become available for the month of March 1952. These show a total of sales by electric utilities to ultimate consumers in the United States of slightly over 29 billion kilowatt-hours, an increase of 8.4 per cent over March 1951. Total sales for the twelve months ended March 31, 1952, amounted to over 333 billion kilowatt-hours; an 11.4 per cent increase over the preceding twelve months. The greatest percentage gain in sales was to residential consumers, although industrial sales were up about ten per cent over the corresponding period of 1951. The greatest increase in sales to ultimate consumers was in the west south central states where the figure was 22.3 per cent; whereas New England showed the smallest of only 4.5 per cent.

Operating revenues of the larger privately owned electric utilities for March 1952 were up 8.1 per cent over March 1951, against which there were increases in operating expenses of 4.2 per cent, including a 3.3 per cent increase in fuel cost. However, for the twelve-month period the operating expenses were up more than 7 per cent. Taxes chargeable to electric operations increased 11.7 per cent.

At the end of March 1952, the net investment in electric plant amounted to $16,866,614,000, as compared to $15,320,245,000 one year earlier.

The late Thomas E. Hanley

We regret to announce the death of Thomas E. Hanley, circulation manager for COMBUSTION since its inception in July 1929. He passed away on May 16 at the age of 59. A native of Washington, D.C., Mr. Hanley was well known to readers of this publication who may have had occasion to contact him in regard to changes in address, requests for copies of back issues, etc. His early experience in the passenger and freight-traffic departments of several railroads was interrupted by service in the Corps of Engineers during World War I, where he served in France and rose to the rank of master sergeant. For many years he also acted as assistant secretary-treasurer of the Industrial Advertising Association of New York.

Use of Ultrasonic Coagulator with a Cyclone Separarot

Results of preliminary investigations conducted at Purdue University to determine the effectiveness of high-frequency steam-jet-induced vibrations in coagulating particles of dust and smoke. The device was attached to the breeching of the power plant stack.

By J. R. KREBS* and R. C. BINDER†

CERTAIN high-frequency or so-called "ultrasonic" vibrations show real promise of being able to coagulate very small particles of dust, smoke, or fog suspended in a gas. Various possibilities have been indicated by laboratory studies. Power plant and other engineers have raised questions as to the application of these vibrations to full-size, practical, plant cases.[1]

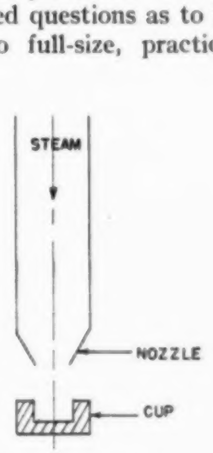


Fig. 1—Diagram of ultrasonic vibrator

There are questions as to the design, performance, and the economy of ultrasonic coagulators.

In an attempt to answer some of the questions on technical design and performance, a model dust collector was installed at the breeching leading to the stack of the Purdue University heating and power plant. The collector consisted of an ultrasonic coagulator in series with a cyclone separator. The following describes the equipment and tests, and summarizes the results obtained.

Description of Equipment

The ultrasonic vibrator was of the jet type, as illustrated in Fig. 1. Steam flows through a converging nozzle into the atmosphere, with the critical pressure existing at the nozzle throat. The fluid leaving the nozzle strikes a cup. Since the throat pressure is greater than atmospheric, the flow immediately downstream from the throat continues to expand until the pressure drops to some value below atmospheric; the flow beyond this point is suddenly retarded, and the pressure rises. As a result, a high-frequency or ultrasonic vibration is generated in the region between the cup and nozzle. Some dimensions are critical. For example, a small change in the distance between cup and nozzle may result in a large change in the intensity of the ultrasonic wave; this distance was regulated by a micrometer head.

Certain optimum factors were determined by laboratory measurements. The inlet steam pressure was 60 psig; the throat diameter of the nozzle was $^3/_{16}$ in.; the cup had an inside diameter of 0.248 in. and a depth of 0.112 in.; and the distance from cup to nozzle was 0.35 in. The vibrator operated at a frequency of about 20,000 cycles per second.

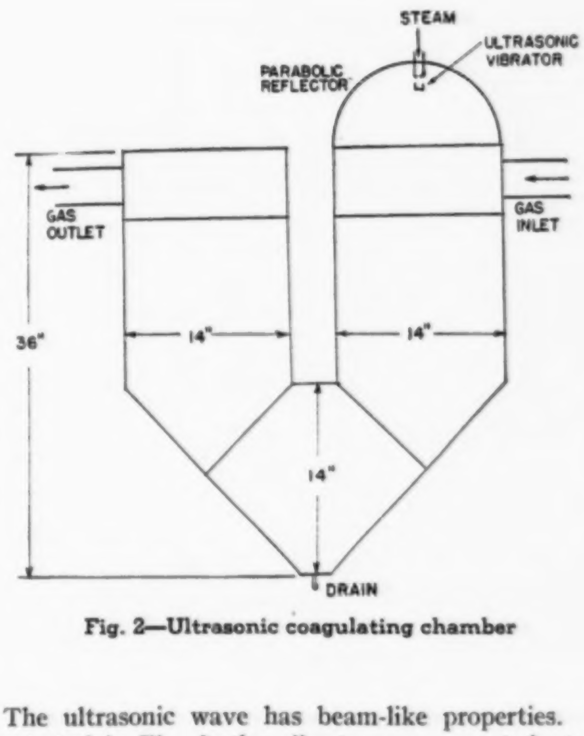


Fig. 2—Ultrasonic coagulating chamber

The ultrasonic wave has beam-like properties. As illustrated in Fig. 2, the vibrator was mounted at the focus of a parabolic reflector which, in turn, was mounted on one end of a U-type structure. The other end of the U was closed to provide a flat reflector. This arrange-

[1] Ultrasonic coagulation has been the subject of numerous investigations over the past few years, as applied to various materials; but in general they seem not to have come up to the more optimistic expectations. The tests on stack gases at Purdue as here reported, although not conclusive, represent one more step toward accomplishing the objective.—EDITOR

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† Professor of Mechanical Engineering, Purdue University, West Lafayette, Indiana.

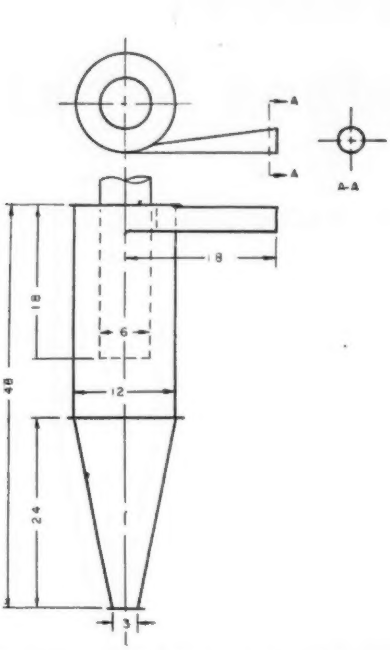


Fig. 3—Dimensions (in inches) of cyclone separator

ment, with the lower diagonal walls, gave a resonating chamber. The smoke was led in at one side of the U and discharged from a side outlet in the other leg.

Fig. 3 illustrates the cyclone separator, and Fig. 4 the general arrangement. Stack gases from the breeching were led into the ultrasonic coagulation chamber and from there the flow passed through the cyclone separator. The pressure regulators in the steam line were used for obtaining the optimum pressure at inlet to the nozzle.

The function of the ultrasonic coagulator is to agglomerate small particles. Initially, these particles may be as small as 0.005 micron in diameter. In the coagulation process many will agglomerate to a size large enough to be effectively removed by centrifugal methods. By the addition of the coagulation chamber the effective range of the cyclone separator is extended from about 10 microns downward to approximately 0.005 micron. This combination of coagulator and cycle separator has certain features that might be advantageous. The large range in particle size that can be treated may make the design applicable to a variety of installations. The first cost may be moderate. The operating and maintenance

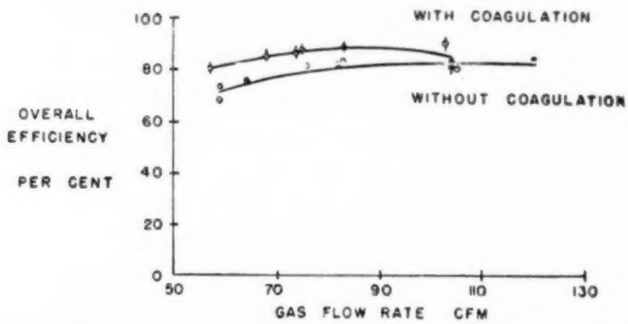


Fig. 5—Dust collector performance, as a function of gas flow rate

costs may be low. The construction and operation is simple and the design may be easily adapted to existing installations.

Measurements

Various tests were made at different flow rates. The rate of flow of gas was measured with a total head tube, a wall static pressure tap, and an inclined manometer. Dust loadings at different outlets were measured with filter bags. The following notation applies to the indicated performance:

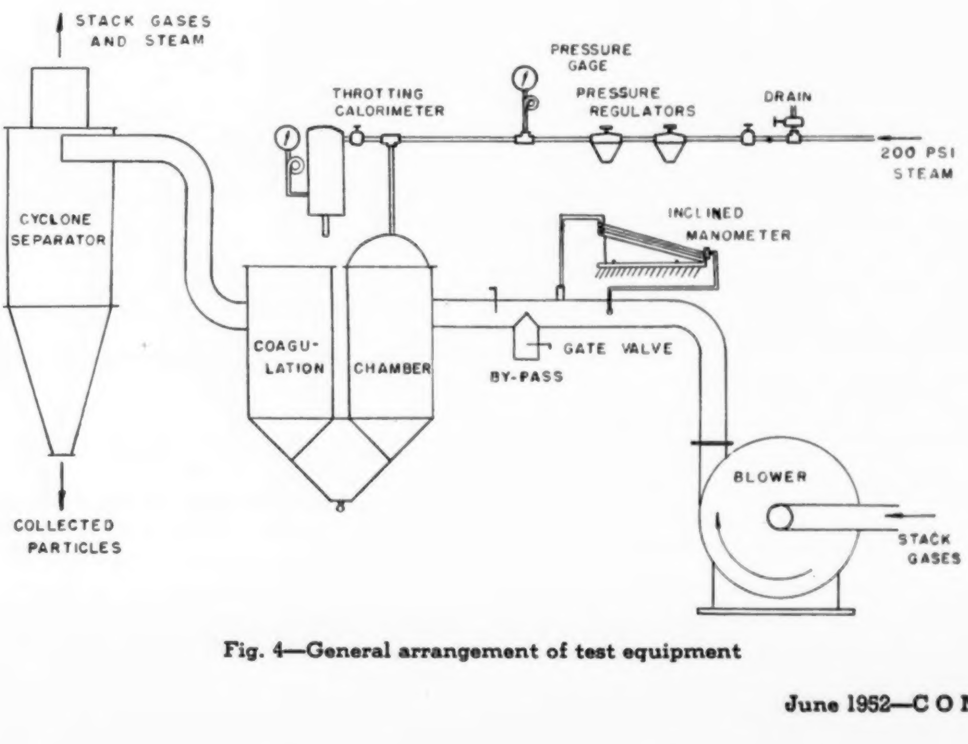


Fig. 4—General arrangement of test equipment

E_o = Overall collection efficiency of the combined unit
E_c = Collection efficiency of the cyclone
W_a = Total dust loading to the combined unit, as in grains per cubic foot of gas
W_c = Dust collected by the cyclone, as in grains per cubic foot of gas
W_d = Dust rejected to the atmosphere, as in grains per cubic foot of gas

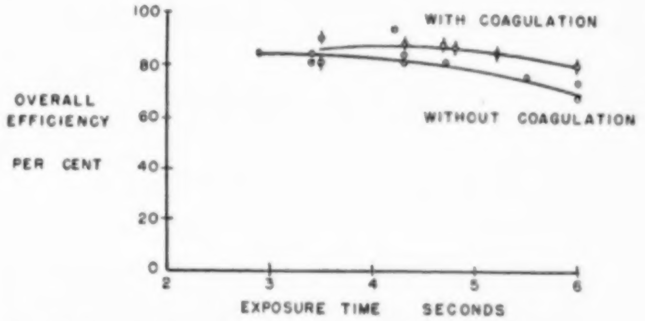


Fig. 6—Dust collector performance as a function of exposure time

The overall collection efficiency E_o of the combined unit of ultrasonic coagulator and cyclone is defined by the relation

$$E_o = \frac{W_a - W_d}{W_a}$$

The collection efficiency E_c of the cyclone alone is defined by the relation

$$E_c = \frac{W_c}{W_c + W_d}$$

Fig. 5 shows a plot of overall efficiency as a function of gas flow rate (cubic feet per minute). Note that the overall efficiency is higher with the ultrasonic coagulator than without. Maximum efficiency is 88 per cent at a

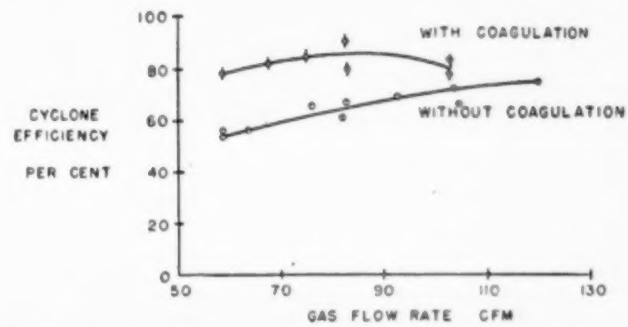


Fig. 7—Cyclone performance as a function of gas flow rate

gas flow rate of about 90 cfm. This represents an increase of 6 per cent over the same unit with the coagulator not functioning.

"Exposure time" is defined as the number of seconds for a unit volume of gas to pass through the coagulator. The coagulating effect is dependent upon the exposure time of the gases to the ultrasonic vibration. This is illustrated by Fig. 6, which is a plot of efficiency versus exposure time. As the flow rate increases, the time that the gases will be exposed to the vibration will decrease. This accounts for the tendency for efficiency to fall at the higher flow rates.

Fig. 7 is a plot of cyclone performance as a function of gas flow rate, and Fig. 8, a plot of cyclone performance as a function of exposure.

The authors are grateful to Prof. H. L. Solberg, Head of the School of Mechanical Engineering, and Prof. A. G. Spalding, both at Purdue University, for their many suggestions and help in arranging facilities. Material in this paper was adapted from a Master's thesis.[2]

[2] "Application of an Ultrasonic Coagulator to a Power Plant," by J. R. Krebs, M.S. thesis, Purdue University, August, 1951.

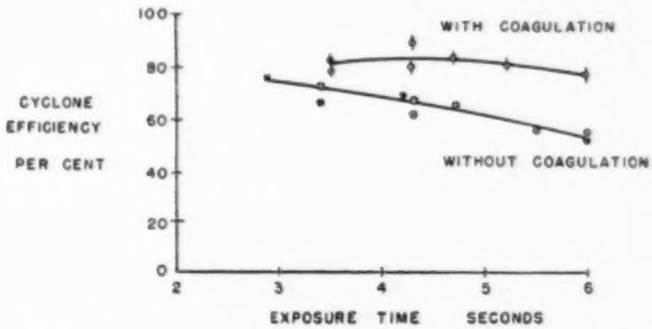


Fig. 8—Cyclone performance as a function of exposure

*Hot Lime Zeolite, A 287 F Installation**

By A. D. SIMPSON

Power Superintendent, Macon Kraft Company, Macon, Georgia

Of the many difficulties encountered in the operation of large paper mills, none is more common than lack of provision for adequate boiler feedwater facilities. It is the purpose of the following to relate how a Southern kraft mill met and overcame this difficulty, with emphasis on the benefits derived from application of high-pressure, high-temperature zeolite softening.

DURING the past two decades, the kraft paper industry in the South has made tremendous strides. Plants designed and erected 15 years ago are producing as much as five times the quantity of paper originally expected. This increased production has been made possible by improved processing equipment, and more of it. Steam and power generation is the very core of production, but seldom did its improvement keep pace with the rest of the plant. Capacities were increased, but not until the demands were so great that additional generation was impossible and the loss of a kilowatt or a pound of steam represented a given amount of paper. Only then was another boiler or turbine-generator added to take care of the immediate exigency, and usually facilities for water treating were ignored or confined to an additional filter and larger pumps. This finally resulted in more feedwater, but generally of lower quality.

As steam pressures and temperatures increased, with greater efficiencies in power generation, feedwater-treating plants were sized to take care of the makeup estimated by the plant designer. However, estimates were usually low and some plants were handicapped from the very beginning.

During the latter period of World War II when paper production had reached an all-time peak, this was accomplished on overloaded feedwater treating plants and at a high boiler maintenance cost. Since this time more significance has been placed on the necessity of better feedwater treatment. As the cost of power plant operation from the standpoint of fuels and maintenance is steadily increasing, more attention is now being directed to this phase. Once an estimate has been made of the ultimate requirements of the overloaded treating plant, it is often discovered that practically a complete duplication may be necessary. This requires large capital investment and more space, with the latter sometimes unavailable and costs difficult to justify.

As one solution to these difficulties, a recent installation was made in connection with an overloaded feedwater treating plant that lent itself to all the previously mentioned problems that exist today in many industrial plants.

The Macon Kraft Company at Macon, Georgia, began production in April 1948, the mill having been designed to produce kraft liner board. It consists of a single paper machine with the highest rated capacity in the world, 600 tons per 24 hr. Production today is carried to a peak of 850 tons.

This also was the first exclusive 900-psig steam generating plant in the paper industry. Prior to this, high furnace temperatures were feared on sulfate liquor burners because of the low heat transfer to waters at high temperatures corresponding to such high pressures. This steam plant consists of five Combustion Engineering-Superheater boilers. These include two pulverized coal and natural gas-fired units of 150,000 lb per hr each, one refuse fuel burner of 100,000 lb per hr, and two chemical recovery units fired with sulfate black liquor and generating 125,000 lb per hr each. The total capacity is 650,000 lb of steam per hour.

All power generating equipment is operated at 850 psig, 825 F, throttle conditions and consists of one 7500-kwhr turbine-generator operating at 160-psig extraction at 40-psig back pressure and two 5000-kwhr condensing units, one extracting at 160 psig and the other at 40 psig. The paper machine is driven by a 2000-hp high-speed geared turbine operating at 160 psig back pressure.

TABLE 1—CLARIFIED PLANT SUPPLY

Total hardness as $CaCO_3$	18–30
Calcium hardness as $CaCO_3$	10–17
Magnesium hardness as $CaCO_3$	8–13
Phenolphthalein alkalinity as $CaCO_3$	0
Methyl orange alkalinity as $CaCO_3$	10–25
Silica as SiO_2	10–15
Sulfates as Na_2SO_4	10–20
Chlorides as NaCl	15–20
Total dissolved solids (calculated)	39–78
pH	7.4
Turbidity	5–10

Water Supply

General water supply for the mill is taken from the Ocmulgee River in amounts up to 18,000,000 gal per day and is clarified with alum and sodium aluminate. This clarified supply provides the source of makeup water to the boiler feedwater treating plant. A typical analysis of the clarified water is shown in Table 1. Characteristics of this water lent themselves to the application of a two-stage hot-process water softener for the purpose of silica reduction, alkalinity correction, and hardness removal. The treatment consisted of caustic soda and magnesium oxide in the first stage followed by disodium

* Presented at American Power Conference, March 26–28, 1952, Chicago, Illinois.

phosphate in the second stage. It was considered practical to utilize directly the 40-psig exhaust steam available for the operation of the boiler feedwater treating plant. The temperature at this pressure, 287 F, was expected to facilitate silica reduction and calcium phosphate precipitation. Accordingly, the station deaerator for softened makeup and condensate was installed as a thoroughfare unit with all steam required for the hot-process softener being passed through the dearator. The design capacity of the makeup water treating system was 220,000 lb per hour and that of the steam-jet deaerator was 700,000 lb per hour delivered output.

TABLE 2

	Clarified Water	Effluent, 1st Stage	Effluent, 2nd Stage	Feed-water	Boiler
Total hardness as $CaCO_3$	12	3.5	0–1	0–1	0
Calcium hardness as $CaCO_3$	7	2	1	0	0
Magnesium hardness as $CaCO_3$	5	1.5	..	0	0
Phenolphthalein alkalinity as $CaCO_3$	0	34	22	17	282
Methyl orange alkalinity as $CaCO_3$	19	59	55	35	364
Hydrate alkalinity (calculated)	..	9	0	0	...
Silica as SiO_2	14	5	3.4	1.7	22
Sulfates as Na_2SO_4	9	8.6	7	3.3	46
Chlorides as NaCl	12	12	12	7	69
Total dissolved solids (calculated)	54	76	99	56	740
Phosphates as PO_4	..	..	8.5	5.5	51
pH	6.8	10.2	9.9	9.9	...

Table 2 illustrates the results obtained under average conditions of operation of this treating system.

With a gradual increase in paper production, greater demand was placed on plant auxiliaries, particularly the boilers and makeup treating system. Steam generation increased an average of 18 to 20 per cent over a relatively short period. An increased demand was placed on the water-treating plant amounting at times up to 35 per cent overload, or 300,000 lb per hr. This necessarily reflected itself in somewhat depreciated feedwater quality and, in particular, the presence of increased magnesium salts. Magnesium phosphate sludges began to accumulate in certain areas of the boilers, especially in the bark boiler where erratic firing was commonplace, and also in sections of the boilers where radiation and circulation were low. It was imperative that this undesirable condition be eliminated in order to maintain the high production requirements of the mill. Table 3 typifies results encountered in spite of efforts to suppress the magnesium.

TABLE 3

	Clarified Water	Effluent, 1st Stage	Effluent, 2nd Stage	Feed-water	Boiler
Total hardness as $CaCO_3$	24	7	5	2	0
Calcium hardness as $CaCO_3$	16	3	1	0–1	0
Magnesium hardness as $CaCO_3$	8	4	4	2	0
Phenolphthalein alkalinity as $CaCO_3$	0	33	33	11	372
Methvl orange alkalinity as $CaCO_3$	21	55	51	22	436
Hydrate alkalinity as $CaCO_3$	0	11	15	0	...
Silica as SiO_2	8.5	1.7	1.7	1	22
Sulfates as Na_2SO_4	12	8.5	11	3.5	98
Chlorides as NaCl	13	13	13	5	99
Phosphates as PO_4	..	...	6	1.5	60
Total dissolved solids (calculated)	58	66	76	34	790
pH	7.5	10.25	10.3	9.75	...

It was not possible without extensive modification of the reaction tank to increase the output of the treating plant. Since the problem at hand was that of the combination of magnesium and phosphate in the secondary softener, elimination of the phosphate by supplementing the primary softener with ion-exchange units seemed to be the most desirable revision, although the operating temperature left some doubt as to the feasibility of the hot zeolite in this instance. However, investigation of existing installations at lower temperature and of laboratory work conducted on the stability of styrene resins at high temperature instilled sufficient confidence in the hot zeolite process to proceed with an installation to operate at this high temperature.

Four 5-ft 6-in. Worthington softeners were installed late last year. These units contain 30-in. beds of styrene resin with regeneration accomplished at the operating temperature corresponding to the prevailing steam pressure. An open-type brine heater supplies approximately 20 per cent sodium chloride which is pumped directly to the ion-exchange unit being regenerated, maintaining pressure of operation at all times to prevent flashing. Slow rinse is carried through the brine distributor at the brining rate and finish rinse is accomplished with filtered water, with a back pressure controller maintaining operating pressure at all times.

Emergency Operation of Zeolite Softeners

Just prior to the startup of the hot-zeolite softeners, an incident occurred that reduced the filtering capacity ahead of the softeners by one third. This caused prohibitive flow rates on the remaining two filters and bypassing was necessary to maintain desired capacity. It was fortunate that the zeolite units were ready to be placed into operation, because a continued flow of feedwater could thereby be maintained without interruption. Operation of the zeolite softeners was continued for about 60 days under these adverse conditions without loss of paper mill capacity with boiler water turbidity lower and blowdown considerably less than previously experienced.

Current with the starting of the hot zeolite plant, treating chemicals to the primary softener were changed to effect lower feedwater alkalinity with a resulting blowdown reduction. Lime replaced caustic soda in the silica-removal operation with magnesium oxide in the first stage. Sodium aluminate assisted in coagulation resulting in improved silica removal. The second-stage phosphate treatment was discontinued. Results of the chemical changes during the first 60 days of operation are shown in Table 4.

TABLE 4

	Clarified Water	Effluent, 1st Stage	Effluent, Hot-Z	Feed-water	Boiler
Total hardness as $CaCO_3$	18	26	1.5	1.3	0
Calcium hardness as $CaCO_3$	10	16	1.4	1.2	0
Magnesium hardness as $CaCO_3$	8	10	0.1	0.1	0
Phenolphthalein alkalinity as $CaCO_3$	0	20	32	12	284
Methyl orange alkalinity as $CaCO_3$	10	26	38	18	352
Hydrate alkalinity as $CaCO_3$	0	14	26	6	...
Silica as SiO_2	14.4	2.6	1.0	Trace	10
Sulfates as Na_2SO_4	19	15	20	3	162
Chlorides as NaCl	14	12	10	4	84
Phosphates as PO_4	...	...	...	..	36
Total dissolved solids (calculated)	48	50	58	22	715
pH	7.4	10.35	10.55	10	...

The treating plant is presently being operated with prefiltration restored but at flow rates greater than anticipated at the time the zeolite conversion was completed. After the prefiltration system was restored to its original capacity, the frequencies of backwashing and regenera-

tion were decreased. An additional filter and zeolite unit will be installed to bring rates for this equipment within conventional practice.

Stability of the styrene cation exchange resin used in this installation which is subjected to temperatures of 285–290 F cannot be determined in such a short time. However, after a period of 60-day contact with conditions prior to restored prefiltration, a total capacity evaluation in the laboratory shows no breakdown of the resin. There was some indication that suspended silica had mechanically fouled the resin during this period, for the samples show the presence of red clay which apparently escaped the clarifier and primary softener in ordinarily unobserved quantities. The superb filtering action of the resin removes this fine clay along with oxides entrained from the hot process softener. Operation on unfiltered water at flow rates of 6 to 8 gpm per sq ft caused excessive pressure drop. However, water quality was excellent with a clearer boiler water persisting. Operation of the plant with prefiltration and a rigid backwash schedule has resulted in maintenance of designed capacity rating. Salt consumption is presently between 0.3 and 0.35 lb per kgr.

Cost of water treatment is a factor given varying considerations. We have taken the month just prior to the hot-zeolite installation as a basis of comparison of operating costs and these figures are shown in Table 5.

TABLE 5—COMPARISON OF CHEMICAL OPERATING COSTS

	Lb. per 1000 Gal	Cost per Lb, Cents	Cost per 1000 Gal, Cents
	A. Caustic-Phosphate		
Caustic soda	0.50	6.0	3.0
Magnesium oxide	0.30	5.4	1.6
Disodium phosphate	0.44	7.75	3.4
Organic	0.28	18.75	5.2
		Total	13.24
	B. Hot Lime-Zeolite		
Lime	0.28	0.77	0.2
Magnesium oxide	0.30	5.4	1.6
Sodium aluminate	0.08	9.8	0.8
Salt	0.4	1.2	0.5
Disodium phosphate	0.08	7.75	0.6
Organic	0.18	18.75	3.4
		Total	7.1

Use of the hot-lime-zeolite process is today being extended to other paper mills, replacing other more costly methods of treatment. From our experience under these conditions on the type of water supply common to this region, we feel that the hot zeolite method is well suited in supplying paper-mill demands. A treating unit is presently being engineered for a new mill comparable in size to our Macon plant (to be located in Rome, Georgia) which will operate at 15 psig and will supply approximately 40 per cent makeup to 900-psig boilers.

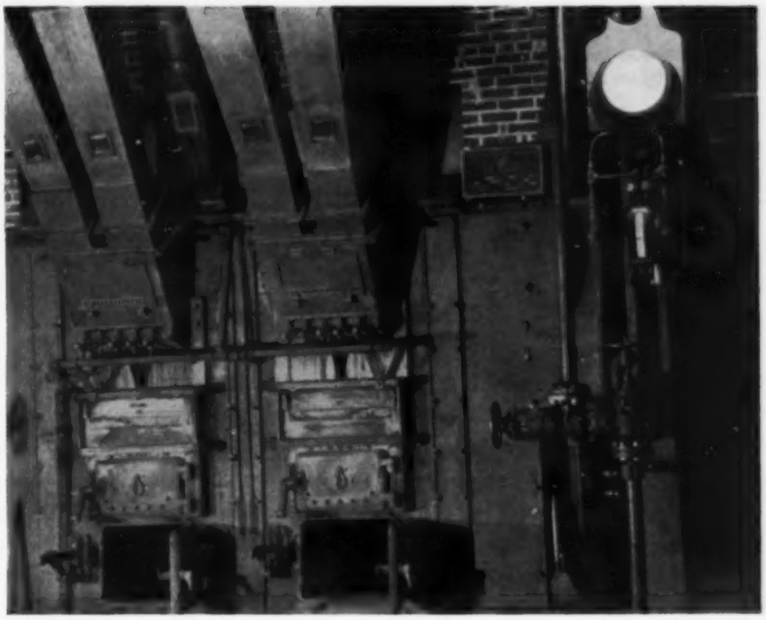
TABLE 6—SUMMARY OF ALL OPERATING CONDITIONS OF HOT PROCESS SYSTEM

Method of Treatment and Conditions	Calcium, Ppm as $CaCO_3$ I*	II†	Magnesium, Ppm as $CaCO_3$ I*	II†	Total alkalinity as $CaCO_3$ I*	II†	Silica, Ppm SiO_2 I*	II†	Boiler Water Blow-down, % of makeup
A (Table 2)	2	1	1.5	0.0	59	55	5.0	3.4	20
B (Table 3)	3	1	4.0	4.0	55	51	1.7	1.7	27
C (Table 4)	16	1.4	10.0	0.1	26	38	2.6	1.0	17

* 1st-stage treatment.
† 2nd-stage treatment.
A: Caustic soda—MgO—followed by phosphate. Design conditions, 1948 to 1950.
B: Caustic soda—MgO—followed by phosphate—high overload conditions, 1950 to 1952.
C: Lime—aluminate—MgO—followed by hot zeolite—inadequate prefiltration.

Improvements in Small Waste-Wood-Burning Plant

Due to the alterations described, this plant was enabled to burn more efficently its wood waste from barrel manufacture and produce more steam for its dry kilns, power generation and heating, and at the same time eliminate a smoke problem.



View of boiler, including controls and fuel feed lines

THE Kimball-Tyler Cooperage Company, Baltimore, Maryland, are an old barrel manufacturing company, having celebrated their one hundredth anniversary several years ago. This company manufactures oak whiskey barrels, sugar barrels, flour barrels, oak beer kegs, etc., and uses large quantities of kiln-dried oak, gum, and other woods as a part of their product. The off-fall, or waste from the manufacture of over 1000 barrels a day approximates 6000 lb of waste fuel per hour, which unless burned in a furnace would have to be hauled away and disposed of at considerable expense.

The old original plant had three small 100-hp, hrt boilers which were fed by a magazine from the various collectors by gravity to the furnace. This resulted in occasional fires in the collectors and magazines, in addition to which it was difficult to comply with the city smoke ordinance.

Harold G. Burrill & Associates were called in first in 1936 to complete the installation of new feeders, collectors, cyclones, wood hogs and conveyors, in order to make one closely knit semi-automatic conveying system. However, due to the War and other causes completion of the boiler room was delayed until 1949 when a new C-E boiler of the sectional-header, cross-drum type was installed, with specially designed automatic feeders. These feeders were so arranged that the delivery of fuel into the furnace was at such a rapid rate that even a small explosion of the fine powdered dust occurring in the furnace caused no backfire through the feeders.

In order to protect the storage magazine and stoker feeders, three fire stops were incorporated, one in the chute going to the boiler injection system, which consisted of a flap-like valve on the top of the pipe, with a screw feeder enclosed in a 14-in. pipe, discharging the fuel into a pipe leading to the injector direct. This screw feeder was operated at variable speeds to compensate for changes in load. The feeder received its fuel from an adjustable worm, or live bottom magazine, which discharged the required amount of fuel to the head of the worm screw feeding the boiler.

Four screws feed the boiler, and are so arranged that two may be operated at part load, and all four may be put in service at full load. Distribution is accomplished by operating feeders 1 and 3 through one variable-speed drive, and Nos. 2 and 4 through the other variable-speed drive, thus distributing the fuel evenly over the grates.

The boiler is arranged for the feeding of coal, or blocks and sticks of wood not handled by the wood-hogging system. It can also handle the material from what is known as a Crozier machine, which grooves the barrel for the receiving of the heads, after they have been charred in the furnace. This charring sometimes leaves fine sparks, which go over to the Crozier, or groove-cutting machine, and is fanned into flame as it passes through the collection system of the Crozier unit. This formerly fed into a large magazine which has been recently removed and required a magazine of its own, discharging directly to the furnace so as to prevent fires in the large unit.

Although designed for an output of 30,000 lb of steam per hour at 250 psig when burning wood, the boiler is being operated at only 150 psig.

The photograph shows the front of the installation which is fully automatic and is controlled by a Brooke automatic control, with an induced-draft fan to provide sufficient draft, and a forced-draft fan to provide the proper amount of air for combustion under the grates, as well as to keep the grates cool under heavy loads.

The new equipment was furnished by Combustion Engineering-Superheater, Inc., and the designs for the feeders, etc., were perfected through the combined efforts of the engineers of that company and the consulting engineers, Harold G. Burrill & Associates. A duplicate design, but of a smaller size, is now being made ready to go into a woodworking plant in Pennsylvania.

This installation provides the company with ample steam for extra dry kilns, ample steam for power generation, new and better heating facilities for the plant at no increased cost of fuel, and considerable reduction in the amount of labor required for handling the off-fall, or waste products. Moreover, the smoke nuisance has been eliminated.

Chemicals, Pipeline Gas and Liquid Fuels from Coal*

By W. C. SCHROEDER

Assistant Director, U. S. Bureau of Mines

This is a review of what has been accomplished toward the production of synthetic liquid and gaseous fuels from coal to supplement those obtained from national sources; also the use of coal as a raw material for numerous industrial chemicals. Underground gasification, developments in hydrogenation and the Fischer-Tropsch process are discussed both technologically and economically.

DURING the centuries that coal has been burned to provide heat, it has been the dream of chemists and engineers that coal ultimately would become the basic raw material for a large portion of the chemical industry. This view was directed not only toward the industrial chemicals such as ammonia, fertilizer, benzene and others, but also reached into everyday life to provide clothing, finishes of all kinds, plastic articles, building materials and a variety of other common commodities. With the growth of the by-product or chemical-recovery type coke oven during the early years of this century, coupled with the development of the water-gas machine, at least part of this vision seemed to be well on the way to realization. The coke plants furnished not only manufactured gas to cook food and to light homes, but also a wide variety of aromatics, dyestuffs and other chemicals. The carbon monoxide and hydrogen produced from coke in the water-gas machine was used as raw material for the production of synthetic ammonia for fertilizers, methanol and other oxygenated compounds.

In the 30's, however, as a result of a great expansion of natural gas and petroleum operations, coal began to lose its position in these fields. Much of the manufactured gas industry was displaced by natural gas transported over long distances through pipelines. New plants, making synthetic ammonia or methanol, turned to natural gas as their raw material, and the older plants, based on coke, began to have trouble meeting the competition from these new plants.

The coke-oven industry held its position so far as iron and steel were concerned because coke remained the best and most economical fuel for blast-furnace operation. The chemicals from this operation continued to flow to commerce, but in many instances were unable to meet the expanding chemical demands because the output was tied directly to the demand for steel. To a considerable degree, the petroleum industry has stepped in to meet some of the demands for aromatic chemicals. So, during the 30's and 40's the early vision of the coal chemists was being pushed into the background, and up to the present time, this new trend is still strong.

Prior to World War II, benzene from coal carbonization was used chiefly as a high-octane blending material in motor fuel, and a relatively minor amount was used for manufacture of chemicals. During the war, because of the need for styrene for synthetic rubber, increased synthetic phenol production and many other chemical developments, this situation changed radically, resulting in the use of greatly increased amounts of benzene for chemical production. At the same time phthalic anhydride production also was increasing, resulting in the use of practically all available naphthalene from coal carbonization for this purpose. These developments were most important in the history of coal carbonization, as far as raw materials for synthetic chemicals are concerned. The increasing demand for benzene finally exhausted this source and now the petroleum industry and imports are supplementing this to some extent, but coal still remains the major source.

Coal for Combustion

While the vision of the coal chemist has not been borne out during the last 20 years, the tonnages of coal that might be used for this purpose are relatively small compared to the amount that is used for combustion. The electric utility industry has always been one of the mainstays in furnishing a market for coal. The growth of this industry since the end of the war has been phenomenal and it has continued to demand an increasing supply of coal. It furnishes one of the bright spots in the postwar coal picture.

In contrast, the railroads have been swept by a program of "dieselization" which has resulted in the loss to the coal industry of a large proportion of this valuable market. At an earlier date, coal suffered somewhat the same loss when the shipping industry turned to oil. Still another valuable market, which is not expanding, is the use of coal for household heating. Here again, oil and natural gas have invaded the markets of coal.

Although it is anticipated that there will be a greatly expanded demand for coal in the next 25 years, even in solid form, to meet accelerated demands for energy, this increase will be largely in extensions of present types of consumer use, such as electric power generation, rather than in the recapture of old markets in the form of a solid fuel.

Work on the coal-burning turbine with respect to its possible application on railroad locomotives deserves mention. Progress has been made in this field and it is now indicated that fuel savings per locomotive, by the substitution of pulverized coal for oil, may amount to as much as $25,000 per year. On the other hand, this saving must be weighed against overall initial cost of the equipment as well as maintenance, operating costs and availability, also the convenience and ease of handling the fuels. It is the overall picture which will determine the fuel the customer will use rather than the savings in fuel costs alone.

The coal-burning turbine has other applications such as for power generation in areas where the water is relatively limited, moreover for stationary purposes there would be no limitation on the size or weight of equipment; hence design problems might be simplified. In fact, coal is suitable for closed-cycle gas turbines, which are in commercial use where space considerations are not as critical as in railway service. The Escher-Wyss closed-cycle turbine, built in Switzerland, is an example.

If coal cannot recapture its markets as a solid fuel, one must look at the fuel industries which are now expanding rapidly in order to evaluate their future as a background to what happened to coal.

* Presented at the Tenth Annual Anthracite Conference of Lehigh University, Bethlehem, Pennsylvania, May 8 and 9, 1952.

Gas From Coal

The natural gas industry has expanded from 1.94 (marketed production) trillion cubic feet in 1930 to 7.4 (marketed production) trillion cubic feet in 1951, an almost fourfold increase. This represents not only the demand for natural gas as fuel transported in long distance pipelines, but the building up of plants for synthetic ammonia, synthetic rubber intermediates, alcohol, and numerous other industries, both along the pipelines and in the gas fields. Despite the enormous demands for natural gas, the known reserves have increased from year to year, although not in such proportion that the overall reserve picture is being enhanced materially. The increase has been due largely to the unprecedented expansion of drilling for petroleum which has also uncovered a great deal of natural gas. However, the market for natural gas is almost insatiable and pipelines cannot be built fast enough to meet customers' requirements. Therefore in many cities, now served by huge pipelines, the installation of further gas heating furnaces is limited or forbidden. It is becoming more and more difficult to tie up sizable blocks of dedicated gas reserves for pipeline or industrial use. Even where reserves are adequate, prices have advanced from 4 or 5 cents a thousand cubic feet in the 30's to 12 or 15 cents at present. In addition, the contracts often contain escalator clauses which can mean price increases in the future.

One of the most interesting developments, which could be indicative of the future trend in the use and price of natural gas, is in connection with the new aluminum plant being built by Alcoa in Milam County, Texas. The power plant for this operation is being built by the Texas Power and Light Company and will have an installed capacity of about 300, 000 to 400,000 kw. Here in the heart of the natural gas area, this power company will burn dried lignite, not natural gas, to generate its electric power. This is not because raw lignite necessarily represents a cheaper fuel at present, but because it promises a cheaper fuel for the long run. The installation is important in still another way for the power plant later plans to install a low-temperature carbonization step ahead of the combustion of the lignite under the boilers. This step will extract tar and other chemicals from the lignite, which it is anticipated will be sold and offer a substantial profit above the cost of processing. The remaining dry lignite char will be burned.

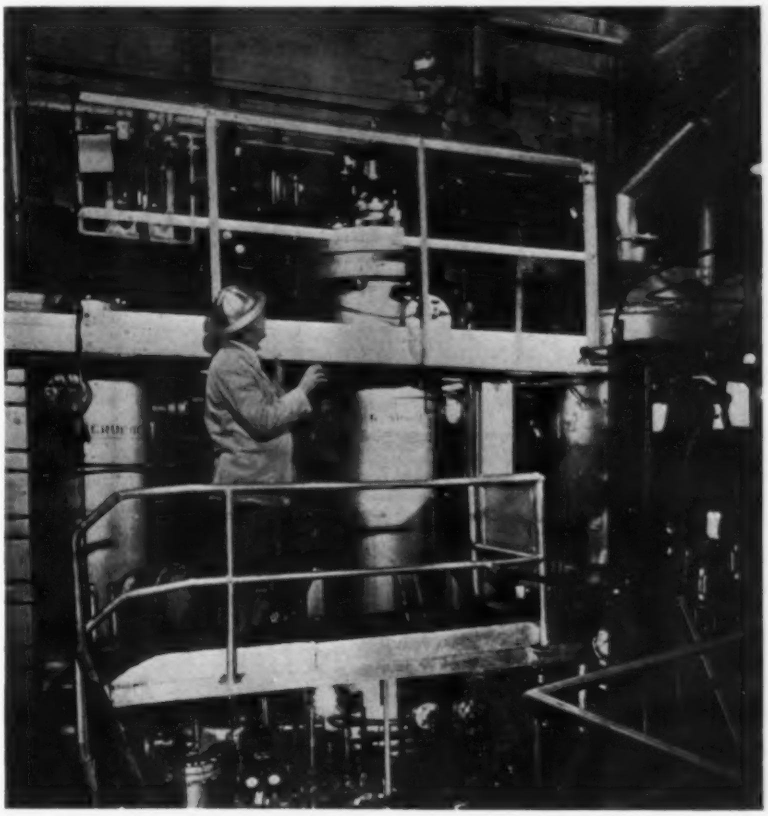
It is indicated from development work conducted by the Bureau of Mines at Denver, Colorado, in cooperation with the Texas Power and Light Company, that lignite can compete favorably with natural gas at present if these valuable tars are extracted from the lignite before burning the char residue for power. The Bureau has developed new methods for drying and carbonizing lignite and other non-coking fuels. One carbonization unit will be incorporated in the new Alcoa plant, and it is expected that the lignite thus used will compete with natural gas at substantially less than 15 cents per thousand cubic feet. Lignite containing 36 per cent moisture can be substantially dried in less than 50 sec, and the tars can be removed in 10 to 12 min by heating in a fluidized bed at 900 F. The processes are continuous and will probably respond to virtually automatic control.

The crude tars produced by this operation are primary products of distillation and contain more than one-third valuable tar acids which are in demand for plastics and other chemical products. About 2500 barrels of tar will be produced per day. The new Alcoa plant at Rockdale, Texas, will be a completely integrated operation. Lignite will be produced by stripping and by underground mining properly balanced to insure continued low costs for many years. The fuel will be moved a few miles by large trucks and introduced continuously into the processing units at the power plant. Some lignite will be stored for standby use but the bulk will be kept moving and will be converted to power in less than an hour after it is mined.

The situation with respect to natural gas is a potential market of such size that known reserves will not be able to satisfy demand for a period sufficient to amortize transmission facilities. Therefore, a steady rise in the price of natural gas, both in the field and as delivered at the end of the pipeline, will allow coal to enter this field. Here again, coal should take its place after it has been converted to the fuel that the customer wants. In other words, the coal should be converted to a high Btu gas for pipeline transmission along with natural gas.

This is now technically possible, but the processes must be considered from the economic standpoint. It would not be economical, under present-day costs and conditions, to start with a coking coal, make coke, and operate water-gas machines and converters, to make a high Btu gas by converting a substantial portion of the carbon monoxide and hydrogen to methane. The difficulties are the cost of coking coal, the cost of shipping it to the plants and the cost of handling in the coke-oven and water-gas steps.

To solve these problems, gasification must be carried out close to the mouth of the mine, it must use coal directly, must produce a gas of nearly 900 Btu per cubic foot and deliver it by pipeline to the market. At present the gas production step has been carried out successfully in pilot plants, the most promising gasification processes for conditions here in the United States involving the direct use of oxygen. In one of these processes, pulverized coal, oxygen and steam are blown into the gasification chamber and react in about a second to produce a gas of some 300 Btu per cu ft. These operations have been carried far enough at the Morgantown Station of the Bureau of Mines, as well as in California by The Texas Company, to provide gas, not only of suitable composition, but under pressures up to 450 lb per square in., and with a surprisingly low raw materials cost. The gas is purified under pressure and then goes through a step called "methanization" which lifts the heating value to around 900 Btu per cu ft. An alternate proposal is to gasify free-burning lump coal, or



Pressure Gasification at Morgantown, W. Va.

char produced from coking coal, by means of oxygen in a Lurgi-type fixed bed generator, operating under pressure, to produce a 450 Btu gas, and raise it to 900 Btu by methanization. There are also other processes available. The estimated cost of the product, including a reasonable profit, is about 55 to 65 cents per 1000 cu ft.[1] This price approaches the present cost of pipeline gas in some areas, but is higher than the cost of gas in many other areas. It is believed, however, that this figure is not the lowest cost that will be achieved for gas from coal or that natural gas will remain at its present price level. It is probable that many potential customers, who cannot now have natural gas, would be willing to pay a slightly higher price to obtain such an ideal fuel.

Pressure Gasification of Coal With Oxygen

The future broadening of markets for coal, as can be seen from much of the foregoing discussion, will depend on the development of a low-cost process for producing synthesis gas (carbon monoxide and hydrogen) directly from coal. The Bureau of Mines has tested several methods for doing this and has found that the process best applicable to all ranks of coal is the one in which pulverized entrained coal is gasified in a mixture of oxygen and steam at pressures up to 450 psi.

The gasification unit shown herewith so far has been operated at pressures up to 300 psi and can gasify as much as 650 lb of coal per hour per cubic foot of reaction space (total volume of gasifier 1$^1/_2$ cu ft). It uses about 9 cu ft of oxygen per pound of coal. Composition of the gas produced is approximately 8 per cent CO_2, 54 per cent CO, 35 per cent H_2, and less than 1 per cent methane. After removal of sulfur impurities this is an excellent raw material for conversion into liquid fuel, chemicals or pipeline gas.

What do these performance data on the pressure gasifier mean in terms of feasibility of commercial-scale operation? First, the feasibility is gaged primarily by costs. The enormous throughputs of 650 pounds of coal per cubic foot hour (in ordinary pulverized coal firing of boilers, only 1 or 2 pounds of pulverized coal are burned per cubic foot per hour) mean that heat losses would be low in a commercial-scale gasifier designed with ordinary water-cooled piping for walls. That is, refractories can be dispensed with, thus avoiding the difficult problem of short refractory life under the severe conditions in the gasifier brought about by high temperatures and slag attack. The high throughputs per cubic foot also mean very low investment or fixed charges for the gasifier per unit of synthesis gas produced. The great part of the total cost is that of raw materials. If coal costs $3 per ton and oxygen 20 cents per Mcf, then the coal cost per Mcf of $CO + H_2$ would be 5.4 cents and the oxygen cost 6.2 cents giving a total of 11.6 cents per unit of synthesis gas produced.

The Bureau of Mines under a cooperative agreement with the Southern Natural Gas Company has found that free-burning lump coal or char can be gasified with oxygen under pressure in a fixed bed producer of the Lurgi type. The gas produced, after methanization, was of a quality which is interchangeable with natural gas. This type of operation requires less oxygen and methanization. These savings, however, may be offset by the higher cost of the free-burning coal or char.

Some explanation is needed as to why it is desirable to carry out the gasification under pressure. Practically all of the operations using the synthesis gas are carried out under pressure and at least 70 per cent of the energy required for compression is saved by carrying out the gasification step under pressure instead of pumping the synthesis gas up to pressure after it has been produced. This is true because the volume of the synthesis gas produced is about 3.5 times that of the oxygen fed to the gasifier in the case of pulverized fuel gasification and still higher in the fixed bed method of gasification. The steam fed to the gasifier can, of course, be generated in a waste-heat boiler. This saving in compression costs amounts to about 3 or 4 cents per gallon on synthetic fuels.

Pressure gasification of pulverized coal with oxygen has a wide tolerance for the type of fuel used. Anthracite, coking or non-coking bituminous coal or lignite can be used as costs dictate. The unit cost of the fuel and its location with respect to markets are the most important factors.

This greatly broadens the range of fuels that can now be considered as raw materials for chemicals, synthetic fuels and pipeline gas. It is also in contrast with earlier methods for using fuel for gas manufacture, in coke ovens, and water-gas machines which were forced to use only the high-grade coking coals. The oxygen gasification processes were developed with this viewpoint in mind for the country's reserves of good coking coals are limited and should be conserved for metallurgical use in so far as economically possible.

While bituminous coal and lignite can be used in the hydrogenation process the higher-ranking bituminous coals are difficult to hydrogenate.

Underground Gasification

The Bureau of Mines has been conducting experiments in cooperation with the Alabama Power Company on the gasification of coal in place. The first two experiments were carried out by mining a sizable passage through the coal, igniting the underground workings and then blowing air through the ignited passage. To keep temperatures from getting too high at the outlet, it was usually necessary to reverse the flow of air periodically. This early work has shown that large quantities of coal can be consumed from an initial passageway without leav-

[1] From "The Timing of an Initial 'Pipeline Gas From Coal' Enterprise," by C. R. Breck, Southern Natural Gas Company, presented 1952 AIME Meeting.

ing any major amounts of combustible materials in the burned area. It was also found that holes could be drilled near the periphery of the combustion zone and additional gas passages developed and coal consumed without further underground work. In the second experiment combustion was maintained continuously for 22 months. During a few intervals, the longest about two weeks, 60 to 110 Btu cu ft gas was obtained. This quality gas may not seem exceptional compared with natural gas, but is good performance for underground gasification. It was not possible to maintain this quality over extended periods in these early experiments. It was also evident that much of the air in the system was bypassing the combustion and reduction zones. In part, this difficulty was traced to the large passages that had been mined in the coal to get the operation under way. Roof falls and subsidence filled these passages with broken rock that allowed the air to filter through without contact with the hot coal surface. Forcing sand into these areas helped prevent bypassing, but it continued to a serious extent.

About the time the reason for these difficulties became clear the Sinclair Coal Company and the Missouri School of Mines reported a method of electrolinking between boreholes drilled to a coal seam which would establish a passage for gas flow between the boreholes without doing any preliminary underground mining. This scheme appeared to be the answer to some of the problems at Gorgas.

Several experiments have now been completed at Gorgas using this electrical method of linking the boreholes. No difficulty was found in applying the method over 152 ft and it is entirely possible that the distance will be increased to 400 to 500 ft between electrodes. At the start, 2400 volts were used to obtain the necessary current flow. As the coal carbonizes, the potential is decreased in order to maintain the needed amperage through the system without overloading the electrical equipment. In the last experiment the current was maintained 120 hr and the total consumption of energy was 71,000 kwhr. It is very likely that in the future both the time and energy requirements will be materially reduced. During this preparatory electro-linking phase a gas having a heating value of 500 to 800 Btu per cu ft was produced with a yield approximating that which would be experienced in coke-oven practice for the carbonization of an equivalent quantity of coal.

When the electro-linking is complete, the electrodes are removed and air is introduced. The initial pressure required to force air through the system is high but decreases as combustion and gasification proceed. Gas quality has been good since this method of establishing the passageway for the gases has been used. At the beginning, the quality of the gas is high with a heating value of more than 150 Btu per cu ft. This falls off over a period of days and the gas composition tends to approach that of producer gas. In the last three months during periods of stable operation, comprising more than two thirds of that time, the gas quality in the experiment at Gorgas has ranged from 50 to 120 Btu per cu ft. A gas analysis typical of the greater portion of this period was: 9.5 per cent CO_2, 0.4 per cent illuminants, 0.2 per cent O_2, 10.9 per cent H_2, 12.1 per cent CO, 1.4 per cent CH_4, and 65.5 per cent N_2. This gas would be suitable for the operation of a gas turbine or a steam boiler. Overall heat recovery in the system is probably as good or better than would be achieved by conventional mining methods followed by combustion above the ground. It is unknown how wide an area of coal can be burned before gas quality falls off. It is estimated that the coal that has been burned out at Gorgas runs to an average width of about 25 ft up to the present time, with the gas quality still good.

To produce a gas suitable for the production of chemicals or other synthesized products by underground gasification, it would be necessary to substitute oxygen for air.

Industrial Chemicals From Coal

Large volumes of industrial chemicals such as benzene, tar acids and other aromatic materials are already produced from coal in high-temperature coking operations. These are not major products and their volume is controlled by the demand for coke. It is possible that the supply of chemicals from coal tar will be augmented by increased low-temperature carbonization operation, the primary field for which appears to be in connection with large power plants, where the char produced can be used directly for steam generation. The process development for such an operation appears to be on the way to success for noncoking coals. Extensive studies of a similar carbonization step have been going on for a number of years on coking coals and there is good reason to believe that suitable methods will be forthcoming. In addition, extensive studies are being made concerning the processing of low-temperature tar to get a large volume of useful chemicals.

Synthesis gas has long been used for the production of methyl alcohol. During World War II and later, methods were developed in Germany and further improved here in the United States, for the direct synthesis of ethyl alcohol as well as higher alcohols from synthesis gas. This has opened up a fairly large chemical field of straight-chain and branch-chain alcohols which will probably depend on coal as their basic raw material in the future.

The gas-synthesis or Fischer-Tropsch process yields considerable straight and branch-chain chemicals which should be considered as side products accompanying the production of synthetic liquid fuels.

The chemicals made from synthesis gas, which have been discussed so far, are those of a straight-chain or branch-chain nature. No successful method has yet been de-

vised for synthesizing aromatic chemicals (ring compounds) from synthesis gas. It has already been noted that the aromatic chemicals in the past have come largely from the carbonization operations and that the supply has therefore been geared to the rate of production of metallurgical coke.

Coal can play a most important part in meeting the demands for aromatics through the hydrogenation process. In fact, if desired, 55 to 60 per cent of the total liquid production from hydrogenation operation can be in the form of chemicals largely of an aromatic nature.

Synthetic Fuels From Coal

The question of when synthetic fuels will be needed in the United States has been the subject of frequent and sometimes heated discussion. Perhaps by approaching this problem from a new viewpoint and basing the discussion only on those factors upon which we can all agree, it will be possible to arrive at an answer that will be quite generally acceptable. The increase in demand for oil in the past few years is one of the unexpected phenomena of our postwar economy. Each year, with the exception of one, has seen the need for oil increase from 5 to 11 per cent over the previous year, until in 1951 the average total demand was about 7,500,000 bbl per day and the estimated demand for 1952 is close to 8,000,000 bbl a day.

This great increase has forced an intense search for every source of supply. There were 44,516 wells drilled in 1951 and it has been estimated that an additional 1000 wells will be drilled during 1952. The search has spread from the traditional and known favorable areas into many states where exploration and development were deferred because of the existence of more readily accessible productive capacity. A great deal of money has been expended in off-shore operations in search of new oil supplies. American companies have reached abroad into Canada, South America, the Caribbean, the Middle East and other areas in the attempt to bring in the necessary supply of oil. The intensity of this effort, the wide geographic application and the huge investment of risk capital which have been made by oil companies indicate the pressure existing and the need for new oil sources.

We still believe that the United States is considered the world's greatest oil nation, with more than a quarter of the total proved reserves (more than any other country) and over half of the world's production and consumption. After a long history of supplying a large share of the world's requirements through exports, the United States has, since 1948, become a net importer and during 1951 was dependent upon foreign sources for 11 per cent of its total new supply. Thus it can be seen that we hold a less dominant position in the world petroleum market. It is likewise expected that the difference between our total consumption and domestic production will increase in the future.

Our oil position, as outlined, and the basic facts underlying this position, are now quite generally accepted. Into this

picture we must try to project the question of coal as a source of liquid fuels. To do this, we must weigh the economics of utilizing coal as a new source of liquid fuels in comparison with other sources such as the extension of the present exploration activities, improved technology in finding oil and in primary methods of production, secondary-recovery methods, drilling on the Continental Shelf, production of liquid fuels from oil shale and importing oil from abroad. If it is found that coal offers about as economical a source of production as any of the other new sources that are being investigated and exploited, certainly it should take its position as a new industry to furnish liquid fuel products. This is one question that concerns us now.

In addition there is a second question concerning security which cannot be evaluated in economic terms. Foreign oil supplies are often international bones of contention that may increase the danger of war. If we are heavily dependent on overseas supplies, their loss in time of war could be a heavy blow to our fighting potential as well as our industrial economy. These factors have too many ramifications to attempt to analyze them in a brief discussion here, but it is important to note that the United States does not have to depend on foreign coal and that oil manufactured from coal would be an assured liquid fuel supply.

Coal Hydrogenation

The coal hydrogenation process was sufficiently far along during the 30's that the Germans were able to build about a dozen large plants which operated throughout the war. They furnished about 90 per cent of the aviation gasoline that was used by Germany in the war period. Extensive studies were made of these operations at the end of the war by the Technical Oil Mission composed of experts from the Petroleum Administration for War, the Bureau of Mines and private industry teamed with similar representatives from Allied powers, particularly the British. On the basis of the information collected, and development studies carried on here in the United States, a coal hydrogenation demonstration plant was built by the Bureau of Mines at Louisiana, Missouri, during 1948 and 1949. The plant, which has a capacity of about 300 bbl of gasoline a day, was first operated in May 1949. Five coals have been processed to date to yield large quantities of motor gasoline and base stock for aviation gasoline. These products have successfully passed extensive tests by the military. The plant has been modified from time to time during this operating period and many new improvements have been incorporated.

This experimental program has been accompanied by detailed cost studies of the operation. The first such study was published by the Bureau of Mines in 1948 on the conventional Bergius process about as operated in Germany at the end of the war. During the past two years these estimates have been revised and reviewed by the Bureau of Mines in collaboration with other groups such as subcommittees of the National

Petroleum Council and private engineering organizations with extensive experience in processing operations of this type. For this conventional plant of 30,000 bbl per day capacity, the Bureau estimated that the cost of the overall liquid product would average about 11 cents a gallon. This figure includes amortization of plant, taxes, social security, as well as other overhead and direct costs. It does not include return on investment, interest and profit. The product from this plant can, in a large degree, be converted to gasoline. However, it is immediately apparent that with gasoline selling at the refinery at about 11 or 12 cents, coal hydrogenation producing only fuels, on this basis, is not now a commercial venture.

It would not be expected, however, that the products from such a plant would be sold entirely as gasoline or fuel, for they contain many valuable chemicals such as benzene, phenol and other aromatics which are worth considerably more than gasoline. Assuming that those chemicals occurring naturally could be extracted and sold, a profit of around 7 per cent could be realized on the equity capital under favorable conditions. It is doubtful if this is sufficient return to attract the necessary capital to the operation unless the plant can be given some tax relief such as an allowance on the product corresponding to a depletion allowance or a government guarantee of price level. The Bureau believes, however, that this is by no means the best hydrogenation operation that is possible. Several ideas have been forthcoming during the past few years which, if incorporated in the design, will cut both the capital investment and the operating costs. In addition, for the initial plant, by the incorporation of some additional equipment, much greater return from chemical products can be realized. Cost calculations on the modernized plant are now being carried out by the Bureau of Mines.

Fischer-Tropsch Process

Investigation of the German synthetic fuel processes at the end of the war showed that country to have gone far in the development of methods for making gasoline, diesel oil and other liquid products from coal by the gas synthesis or the Fischer-Tropsch process. As operated in Germany, the plants synthesized hydrocarbons by the combination of carbon monoxide and hydrogen over a cobalt catalyst. None of their commercial plants operated with an iron catalyst which was in a development stage. For German conditions the cobalt catalyst was particularly useful, since it gave a good yield of high cetane diesel fuel, which they needed. From the earliest preliminary studies made in the United States it was evident that there was a hopelessly inadequate production of cobalt in the world on which to base synthesis production plants of a capacity ultimately required here. This fact, as well as that of cost, turned attention to the development of iron catalysts. The experimental work at the Bureau of Mines laboratories at Bruceton, Pennsylvania,

indicated the need for a fused, granular iron catalyst. Following this laboratory work the Louisiana, Missouri, station installed a production unit and produced 60 tons of catalyst for demonstration purposes at a very attractive cost per ton. In actual runs, this catalyst showed a long life and sustained yield.

The process as operated in Germany was not considered suitable for conditions in the United States. In addition to high costs, Fischer-Tropsch converters used in Germany during the war were of small capacity, generally running 18 to 20 bbl each of liquid product per day. A plant producing 20,000 bbl per day required about 1000 converters, which meant excessive steel requirements and high operating and maintenance costs.

The experimental work here in the United States has been, in a considerable degree, an attempt to surmount these two difficulties. The successful work in the field of pressure gasification and its relation to the Fischer-Tropsch synthesis has already been pointed out.

Based on work performed in pilot and demonstration plants by the Bureau of Mines, a synthesis chamber has been designed to produce about 1000 bbl of product per day per converter. Thus it circumvents this particular deficiency in the German plants.

The Fischer-Tropsch process lends itself very well to being coupled to a coal gasification process. The gas so produced will normally have a hydrogen to carbon monoxide ratio within the range desired when the oil circulation technique of synthesis is employed. With gasification under pressure, i.e., 450 psig, the gas flows to the synthesis step at the desired pressure.

The petroleum industry has devoted a great deal of effort to the modified version of the original Fischer-Tropsch process, and their work, along with that of the Bureau of Mines, has brought it to a point of commercialization. The process looks very promising, and to date most of the equipment and process problems have been overcome. The units have been greatly simplified by American chemical engineering methods. This being a process which is relatively young, even further progress can be expected. The Bureau believes that in the relatively near future, the overall operation using gasification and synthesis will be sufficiently developed for detailed economic studies.

Cost of Coal

This discussion should not be closed without reference to the effect of recent developments of mining operations on the cost of coal. I have heard many industrial people express the belief that the cost of coal has increased as much, and in some instances, more than the cost of commodities in general. For some consumers there is undoubtedly some justification for such a statement, but it must be remembered that it probably combines two factors—one, the cost of the coal itself, and two, the cost of delivering the coal to the consumer. Due to the sharp increase in freight rates since the end of the war, the latter factor

is important. The cost of coal, f.o.b. mines in 1951 was 58 per cent higher than in 1945, and the corresponding increase in average railroad freight rate per ton was 41 per cent. In addition, with respect to the large type of operations that have been considered in this discussion, which will probably consume from 5 to 15 thousand tons of coal per day per plant, the advance in mining technique gives every promise that a modernized mining operation could deliver coal to the plant at relatively low cost.

Conclusions

Technologic development and economic changes during the past 15 years indicate that in the future coal should play an increasingly important part in our fuel and chemical economy. This should be the case not only for its traditional use to provide heat by direct combustion, but also as a raw material for aliphatic and aromatic chemicals, for pipeline gas, for liquid fuels and for ammonia. The overall security position of the Nation will be greatly enhanced by such a change, for the United States is fortunate in having very large reserves of coal.

The pilot plant developments in this field look most promising but as yet no commercial unit is in operation which is applicable to a wide variety of coals.

Acknowledgments

In addition to several members of the staff of the Bureau of Mines who offered many valuable suggestions and additions to this paper, the author wishes to acknowledge the assistance of a number of industry representatives including Dr. A. R. Powell, Associate Manager, Research Department, Koppers Company, and Dr. E. E. Donath, Research Department, Koppers Company, Pittsburgh, Pa.; Mr. C. R. Breck, Southern Natural Gas Company, and Mr. C. W. Connor, Administrator, Defense Solid Fuels Administration.

Obituaries

George W. Eppler, General Manager of the Monongahela Division of Combustion Engineering-Superheater, Inc., passed away on June 8, 1952, at the age of 55.

A mechanical engineering graduate of Carnegie Institute of Technology, Mr. Eppler also studied at the University of Pennsylvania and Duquesne Law School. He joined Combustion Engineering in 1923 and was advanced to general manager in April, 1950. His professional affiliations included the Engineers' Society of Western Pennsylvania and the American Foundry Society. He is survived by his wife.

Fred C. Richardson, mechanical engineer with Westcott & Mapes, Inc., of New Haven, Connecticut, since 1924, died on April 5, 1952, at the age of 65. He had served as project engineer on many important industrial and central-station steam power plants, including the English and Steel Point Stations of The United Illuminating Company. A member of the American Society of Mechanical Engineers, Mr. Richardson is survived by his wife, Hannah R. Richardson.

Some Early Work in Steam

The following excerpts from the presidential address of G. E. Foxwell on "Fuel Technology and Civilization" before The Institute of Fuel (Great Britain) on April 23, 1952 are of considerable historical interest:

"The force of expanding and condensing steam has been known since ancient times. Sir Samuel Morland (1625–1695) made the first accurate quantitative measurement of the volume of steam generated from a given volume of water. In 1698, Captain Thomas Savery devised his *fire engine* and presented a model of it to King William III. It was a contrivance in which steam from a boiler was led into a tank in which it was condensed by external cooling. The vacuum created drew in water which was then forced out and upwards by the boiler pressure; valves on the inlet and outlet pipes were manipulated as required. The engine was effective, when the boiler did not burst, but very inefficient thermally, partly from bad construction but fundamentally because the steam was brought into contact with the cold water that it pumped.

"A few years later (1705 or 1706) a blacksmith, Newcomen, and his partner, John Calley, both ignorant of mathematics and the principles of physics, devised an improvement which avoided direct contact between the steam and the cold water to be lifted. A beam of timber, high above ground level and solidly supported, was pivoted and free to swing through an arc vertically. Steam was admitted to a vertical cylinder attached to one end of the beam and condensed therein by a cold-water spray, the motive power thus being due to the vacuum created. The alternate admission and condensation of steam created a regular slow to-and-fro motion which worked the pump. This combination of fire engine and water-wheel soon spread all over the country. It was still a highly inefficient machine but no one seemed able to rectify its fundamental defects, though constructional defects were reduced as time went on.

"An important difficulty faced both Savery and Newcomen—that of constructing a safe boiler and cylinder. Newcomen improved Savery's construction by replacing the brass cylinders and lead pipes of early engines with cast-iron materials.

"The development of power had hitherto been a matter for the practical man, but now science took a hand. Cullen published only one original paper: 'On the Cold Produced by Evaporating Fluids.' This influenced his pupil and successor, Joseph Black, professor of medicine and chemistry, a practicing medico with a large practice. As early as 1756, Black had begun to meditate on the surprising slowness with which ice melts and with which water is dissipated on boiling. He noted that a large amount of heat is adsorbed by a solid at its melting-point which does not register on a thermometer. From that he drew a distinction between heat and temperature and thus discovered the existence of latent heat. He then set

out to meaasure the amount of heat thus rendered hidden or latent. In December, 1761, he showed that when a defined quantity of water freezes it gives up an amount of heat equal to the amount absorbed or rendered latent during liquefaction. By the summer of 1764 he had satisfied himself on the precise quantity of the heat latent in steam, though he never published his findings but contented himself with using the material in lectures to his students. From this work, too, resulted his discovery of specific heat.

"In 1764 he was joined by a pupil, one James Watt, employed at Glasgow University Observatory on the repair and maintenance of instruments—quite an ancient profession, it will be observed. There happened to be a model of Newcomen's engine there which should have worked but did not, and which Watt was asked to repair. Watt had the advantage, which Savery and Newcomen had not, of guidance from Black. Watt in 1763 had made some experiments to ascertain why the Newcomen model failed to work. He measured the volume of steam produced when a known weight of water was evaporated and also the weight of water used for each stroke. He showed that the volume of steam consumed for each stroke was four times the volume of the cylinder. Black would doubtless point out to him from his knowledge of specific heat that there was considerable waste of steam through cooling the cylinder by water used to condense the steam, and that steam was therefore used in heating the cylinder at each stroke. Watt wisely made some measurements and found that, in condensing, steam gave out enough heat to raise five times its weight of water to boiling-point. This result he found inexplicable until Black explained it to him through reference to his own discovery of latent heat in 1761. Black contributed both money and advice. In May, 1765, Watt records, 'I had gone to take a walk on a fine Sabbath afternoon. . . . I was thinking upon the engine . . . when the idea came into my mind that, as steam was an elastic body, it would rush into a vacuum and if a communication was made between the cylinder and an exhausted vessel, it would rush into it, and might be there condensed without cooling the cylinder. I then saw that I must get rid of the condensed steam and injection water if I used a jet as in Newcomen's engine.'

"Watt, like a good Scotsman, observed the Sabbath. He waited till Monday morning to begin the construction of the first steam engine with a separate condenser. Power produced from coal through steam was on the way.

"By 1768, Black could no longer finance the experiments on the scale needed. His share was taken over by Roebuck, of the Carron Ironworks. In 1773, Roebuck failed through having fingers in too many pies. Watt's wife died. He left Glasgow to go into partnership with Matthew Boulton in Birmingham, where the steam engine was further developed. By 1835 there were in Britain 1953 steam engines and only 1297 water-wheels. Steam, as the medium of power, was the most important single factor in the industrial revolution."

REVIEW OF NEW BOOKS

Any of the books here reviewed may be secured through Combustion Publishing Company, Inc., 200 Madison Ave., N. Y.

Engineering Thermodynamics

By Newton C. Ebaugh

The Second Edition of this college text incorporates a number of additions and improvements without changing the basic over-all purposes of the earlier edition, i.e., to set forth and explain the elementary essentials of thermodynamics as they apply to modern industrial equipment. Fundamental data from which the student may gain a working knowledge of thermodynamic processes are presented in the first eight chapters; various fields of application are discussed in the remaining nine sections.

There are many features that recommend this book to the practicing engineer as well as the student. The author is to be commended for his inclusion of two tables based on the recommendations of the American Standards Association, one listing symbols and the other, abbreviations. It is to be hoped that the teaching of standard notation at the undergraduate level may ultimately reflect itself in a higher quality of technical papers, particularly insofar as commonly accepted symbols and abbreviations contribute to more widespread and easier understanding of engineering terms.

Mollier charts for steam, ammonia and air and a psychrometric chart are included in a rear pocket of the book. Answers to a few typical problems are provided, and each chapter contains a short bibliography. In addition, the author has not only acknowledged his indebtedness to a number of outstanding thermodynamic texts, including those by Kiefer and Stuart, Lucke, Barnard-Ellenwood-Hirshfeld, and Goodenough; but he has also made use, with appropriate credit lines, of some of the outstanding features of these well-known works in the thermodynamic field.

All in all this is an outstanding book which deserves wide use. Containing 398 pages, it sells for $5.75

Specifications for Steel Piping Materials

The 1952 edition of this compilation contains in their latest approved form the 56 widely used ASTM specifications for carbon-steel and alloy-steel pipe and tubing, including stainless. Materials covered include: pipe used to convey liquids, vapors, and gases at normal and elevated temperatures; still tubes for refinery service; heat-exchanger and condenser tubes; boiler, superheater, and miscellaneous tubes. To make the volume more complete there are also included specifications for the following materials used in pipe and related installations: castings; forgings and welding fittings; bolts and nuts. The ASTM standard classification of austenite grain size in steels with two sets of charts; also the American Standards covering wrought steel and iron pipe and stainless steel pipe are a part of the book.

New specifications cover: seamless and welded steel pipe and tubes for low-temperature service; seamless ferritic alloy steel pipe for high-temperature service; forged or rolled carbon and alloy steel flanges, forged fittings, and valves and parts for low-temperature service; ferritic and austenitic steel castings for high-temperature service; ferritic steel castings for pressure containing parts suitable for low-temperature service.

Numerous emergency alternate provisions applying to specifications in this compilation have been issued and are furnished with this volume.

This book should be of distinct service to those concerned with pressure piping, power generation, the petroleum field, the distribution of gas, oil, water, etc., and to individuals in every industry where these materials are important. There are 384 pages, with heavy paper cover, and the price is $3.50.

Industrial Heat Transfer

By F. W. Hutchinson

Solution of problems on heat transfer between industrial fluids involves the solution of complex formulas as well as time-consuming determination of viscosity, specific heat and density of the fluids. To simplify this, F. W. Hutchinson, professor of Mechanical Engineering, University of California, has originated "Industrial Heat Transfer." The feature of this book is 128 working charts from which a direct solution of heat-transfer problems can be obtained for 70 industrial fluids ranging from air and acetylene to sulfur dioxide and water. These graphs are equal in accuracy to the equations from which they are derived.

The book includes considerably more than the graphical solutions. As a further aid, the page opposite each graph gives the equation for the graph, its limitations, its extension and the references to the discussion of that equation in the text. An actual example is given, and its solution is shown on the graph. Examples have been selected which not only demonstrate the use of the graphs, but also illustrate typical solutions of heat transfer problems. The book is printed on a special hard-finish paper to permit pencil construction lines to be made directly on the pages and erased after the problem is solved.

At the beginning of each chapter the fundamental theory is discussed and the equations relating to the evaluation of heat-transfer coefficients and rates are developed; at the end are presented the graphs.

The six chapters are: introduction, conduction, radiation, convection, combined heat transfer, and forced convection. That on forced convection will be of particular value to the practicing engineer since it covers forced convection of gases and liquids whether heating or cooling within or outside of pipes.

The book is a valuable text for students of heat transfer, and a useful working handbook for practicing engineers who must make accurate calculations of heat-transfer coefficients and rates in designing or specifying actual installations.

Bound in green buckram, it is 6 × 9 in., has 336 pages and is priced at $6.00.

Measuring Productivity in Coal Mining

By Charles M. James

A growing source of useful information on economic trends having a bearing on long-range engineering planning is found in the publications of the graduate schools of business of many of our universities. A good example is this research report, subtitled "A Case Study of Multiple Input Measurement at the County Level in Pennsylvania, 1919–1948," prepared by the Industrial Research Department of the Wharton School of Finance and Commerce of the University of Pennsylvania.

The report is of interest to those concerned with problems of productivity measurement generally and in specific application to the mining industries and to those having a stake in coal economics, which includes many engaged in the design, operation and planning of steam power plants. The author shows that conventional measures of productivity in the coal industry—tons per man, tons per man-day and tons per man-hour—embrace too many simultaneous influences without taking into consideration such factors as the very different techniques and production results of underground as contrasted to strip mining, the thickness of seams being mined, and the effects of such tangible and intangible factors as overhead, labor relations, and engineering and managerial skill.

Mr. James, in the report, proposes to change conventional measures of productivity so that his research follows these patterns: (1) The scope of the inquiry is narrowed from the coal industry of the United States to a part of the industry in which the principal characteristics of the mining operations can be standardized and held constant over the entire area. (2) The scope is broadened to cover not only the number of man-days required to mine a ton of coal but also to include all non-labor input ratios for which statistical indicators can be found. Since these two changes are logically independent, they may be used separately, although the author believes that better results may be achieved by employing them in combination.

The content of the research report is suggested by these representative chapter titles: Man-day and Man-hour Measurements, The Bearing of Geological Conditions Upon Labor Requirements, Statistical Measures of Inputs, and Mechanization and Labor Requirements.

There are 96 pages in this paper-bound report which sells for $2.

Standards on Refractory Materials

The 1952 edition of the ASTM Manual of Standards on Refractory Materials brings together in their latest approved form the 37 ASTM standard and tentative specifications, classifications, test methods, and definitions pertaining to refractories. It includes other pertinent information of value in the testing and use of refractories not in the category of ASTM standards, such as a suggested procedure for calculating heat losses through furnace walls; suggested practice for use with ASTM panel spalling tests; suggested petrographic techniques; standard samples for chemical analysis and pyrometric cone equivalent determinations; and 12 industrial surveys of refractory service conditions.

New material includes methods of test for modulus of rupture and for permanent linear change on firing of castable refractories; a proposed test method for disintegration of fireclay refractories in an atmosphere of carbon monoxide; a survey of refractory service conditions in the incineration of refuse; and a very extensive proposed glossary of terms relating to refractories, their manufacture, and use. In addition to the usual table of contents and that of numeric sequence there is a subject index and an author index.

This book of 292 pages is priced at $3 per copy bound in heavy paper and $3.65 when bound in cloth.

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